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Fostering Students' Critical Mathematical Thinking on Linear Equations through STEAM-Based Water Filtration Projects

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Abstrak
Penerapan Project-Based Learning (PjBL) berpotensi mengembangkan berpikir kritis, namun integrasi masalah nyata seperti mitigasi bencana masih jarang dilakukan. Penelitian ini bertujuan menguji keefektifan proyek mitigasi filter air berbasis STEAM dalam menumbuhkan kemampuan berpikir kritis siswa. Menggunakan desain eksperimen murni posttest-only control group, penelitian ini melibatkan 58 siswa kelas VII SMP Negeri 3 Kembang Jepara yang dipilih melalui cluster random sampling. Kelompok eksperimen menerapkan proyek STEAM, sementara kelompok kontrol menggunakan pembelajaran konvensional. Data dikumpulkan melalui tes hasil belajar dan angket respons, lalu dianalisis menggunakan uji independent t-test. Hasil penelitian menunjukkan bahwa kemampuan berpikir kritis siswa pada kelompok eksperimen secara signifikan lebih baik dibandingkan kelompok kontrol. Temuan ini menegaskan bahwa proyek mitigasi filter air berbasis STEAM efektif mengembangkan berpikir kritis serta keterampilan abad ke-21 (kreativitas, kolaborasi, dan komunikasi). Integrasi matematika dalam konteks dunia nyata melalui proyek STEAM menjadi strategi krusial untuk menumbuhkan kepedulian siswa terhadap isu mitigasi bencana.
***Kata Kunci**: Berpikir Kritis Matematis; STEAM; Mitigasi; Project-based Learning; Keterampilan Abad 21.*

Abstract
While Project-Based Learning (PjBL) is recognized for its potential to develop students' critical thinking, the integration of real-world contexts, particularly disaster mitigation, remains underexplored. This study aims to evaluate the effectiveness of a STEAM-based water filter mitigation project in fostering students' critical thinking skills. Employing a true experimental posttest-only control group design, the study involved 58 seventh-grade students from SMP Negeri 3 Kembang Jepara, selected via cluster random sampling. The experimental group implemented the STEAM project, while the control group received teacher-centered conventional instruction. Data were collected through achievement tests and student response questionnaires, followed by independent t-test analysis. The findings reveal that students engaged in the STEAM-based project demonstrated significantly higher critical thinking skills than those in the conventional group. This study confirms that STEAM-based water filter mitigation projects effectively develop critical thinking and reinforce 21st-century skills, including creativity, collaboration, and communication. Furthermore, integrating mathematics into real-world contexts through STEAM serves as a crucial strategy to enhance students' awareness of disaster mitigation issues.
Keywords: Critical mathematical thinking; STEAM; Mitigation; Project-based Learning; 21st-century skills.

I. Introduction

The primary challenge of 21st-century education is ensuring quality learning outcomes (Dubey, 2024). To succeed in the 21st century, students are expected to acquire six fundamental competencies, widely recognized as the 6Cs—critical thinking, collaboration, communication, creativity, citizenship, and character education (Bulkis et al., 2025; Zainil et al., 2024). Serving as a core foundation, these competencies help students develop the capacities needed to thrive in an increasingly interconnected global context. Among these six skills, critical thinking stands out as a crucial ability that should be nurtured from an early age (Setiana & Purwoko, 2020). Critical thinking is an active and systematic intellectual process involving the formation, application, analysis, and evaluation of knowledge and concepts (Lianti et al., 2023). It empowers students to generate innovative ideas, solve problems effectively, and draw logical conclusions from various possibilities (Chukwuyenum, 2013; Nurfitriani & Subekti, 2024; Syafitri et al., 2021; Wasqita et al., 2022). Additionally, strong critical thinking skills enable students to think rationally and make well-informed decisions (Jumaisyaroh et al., 2015; Romadhoni et al., 2024; Pramasdyahsari et al., 2024a).

Critical thinking is a key competence for 21st-century learners; however, Indonesian students' critical thinking abilities in mathematics are still limited. This condition is reflected in the 2018 OECD PISA results, which positioned Indonesia at 73rd of 80 countries in the mathematics domain. The country's average score declined from 386 in 2015 to 379 in 2018 (Salvia et al., 2022). Similarly, in 2011, Indonesia's performance in the Trends in International Mathematics and Science Study (TIMSS) positioned the country 38th of 42 participating nations, with a mean score of 386, and this outcome is consistent with evidence reported in prior research findings (Habibah & Marlina, 2023; Pramasdyahsari et al., 2023; Rosmalinda et al., 2021). The persistence of low critical thinking skills among Indonesian students calls for targeted and effective interventions. Mathematics education, in this regard, serves as a key domain for nurturing and strengthening students' critical thinking abilities.

An effective approach to promoting critical thinking in mathematics is to design learning activities centered on problem solving, where students work individually and collaboratively and take an active role in constructing their understanding (Firdaus et al., 2019; Rooney, 2012). This aligns with the objectives of mathematics education outlined in Permendiknas No. 22 of 2006. However, many students still perceive mathematics as difficult and intimidating, primarily due to their struggles in applying mathematical concepts to real-life situations (Mazana et al., 2018). One effective approach to addressing this issue is through 21st-century learning models, particularly contextual learning (Badan Standar Nasional Pendidikan, 2010). Contextual learning connects instructional material to students' real-world experiences, making concepts more meaningful and applicable (Berns & Erickson, 2001). To foster critical thinking, teachers must implement contextual learning strategies. However, in practice, many classrooms still rely on teacher-centred instruction, which limits students' opportunities to develop their critical thinking skills (Handriani et al., 2017).

One effective contextual learning method that can be implemented is the STEAM (Science, Technology, Engineering, Arts, Mathematics) approach. The STEAM approach combines science, technology, engineering, arts, and mathematics, helping students see how these disciplines are connected to one another (Estriyanto, 2020; Mu'minah & Suryaningsih, 2020; Setyawati et al., 2022; Quigley et al., 2017). In this way, the approach supports 21st-century educational goals that call for learners to develop a holistic view of the world (Barkah et al., 2024; Iaskyana et al., 2022). By engaging students in hands-on design activities and product development, the STEAM approach helps nurture creativity alongside problem-solving competence (Ayuningsih et al., 2022; Liao, 2016). It not only enhances students' mathematical abilities but also encourages them to apply their ideas in real-world contexts (Mansyur et al., 2024; Pramasdyahsari et al., 2024b; Pramasdyahsari et al., 2025a; Pramasdyahsari et al., 2025c; Sari & Sutihat, 2022). Through STEAM-based project learning, students can explore mathematical concepts in engaging and meaningful ways, making learning more relevant and applicable to their everyday lives (Pramasdyahsari et al., 2025a; Pramasdyahsari et al., 2025c; Ranak et al., 2023).

- Through project-based learning, students are encouraged to develop critical thinking as they work individually and in groups to address real-world problems drawn from their surrounding environment. One significant challenge often encountered is disaster mitigation. Given Indonesia's vulnerability to natural disasters, it is essential to introduce disaster mitigation concepts to students, helping to cultivate a generation that is resilient and well-prepared for such events (Pahleviannur, 2019; Suarmika & Utama, 2017). Despite its importance, the integration of STEAM with disaster mitigation in mathematics learning remains limited (Alfirda et al., 2025; Pramasdyahsari et. al., 2025b). In light of these considerations, the present study explores the impact of disaster mitigation-oriented STEAM project learning on the development of students' critical thinking skills.

II. METHOD

A true experimental design is used in this study to examine causal links between variables through the control of potential confounding factors (Creswell, 2014; Sugiyono, 2013). A true experimental posttest-only control group design was applied in this study to explore the influence of a STEAM-based water filtration project on students' critical mathematical thinking. The project served as the independent variable, while critical mathematical thinking was treated as the dependent variable, and posttest performance between groups was compared to identify potential effects (Creswell, 2014). This study involved a population of 224 seventh-grade students from seven classes at a public junior high school in Jepara. Using cluster random sampling, intact classes were designated as clusters and randomly selected to represent the sample (Creswell, 2014). Fifty-eight students took part in this study, with Class VII A (n = 29) assigned to the experimental group and Class VII B (n = 29) serving as the control group. The experimental group experienced STEAM-based mitigation project learning, while the control group followed teacher-centred instruction. The study was implemented through three phases, namely observation, learning implementation, and posttest evaluation.

The control group received instruction using a teacher-centred learning (TCL) approach. Instruction was delivered over six sessions, each lasting approximately 80 minutes. Learning activities typically began with a teacher explanation of concepts related to linear equations, followed by worked examples demonstrated on the board. Students then completed individual exercises from the textbook or worksheet under teacher supervision. Question-and-answer interactions were primarily teacher initiated, and tasks focused on applying formulas and procedures to routine problems. No project work, engineering design activities, or extended collaborative problem-solving tasks were included.

Meanwhile, the experimental group participated in STEAM-based water filtration mitigation project learning over six sessions of approximately 80 minutes each. Students worked in small groups to identify water quality problems, design filtration prototypes, select materials, construct and test their designs, analyze results, and refine their solutions. The learning process followed an engineering design cycle consisting of problem identification, planning, building, testing, evaluation, and redesign. The teacher acted as a facilitator by providing guiding questions, feedback, and conceptual support.

This study was conducted in accordance with ethical research principles. Permission was obtained from the school administration before data collection. Students were informed about the purpose of the study, participation was voluntary and students' identities were kept confidential. All data were used solely for research purposes.

This study employed two data collection instruments: a critical mathematical thinking test and a student response questionnaire. Students' critical mathematical thinking was assessed using a two-item open-ended test that had been validated by experts and reviewed for readability. Posttest data were analyzed using descriptive statistics to determine mean scores and score distributions across groups. Following the verification of normality and homogeneity assumptions, differences between groups were analyzed using an independent samples t-test to evaluate whether participation in STEAM-based mitigation project learning led to higher critical mathematical thinking. All statistical analyses were performed using statistical software with a significance level set at $\alpha = 0.05$.

In addition, a student response questionnaire was administered to participants in the experimental group after the posttest to capture their perceptions of the STEAM-based water filtration project. Student responses were classified as positive when the percentage of favourable responses exceeded 70%.

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III. Result and Discussion

During the project-based learning process, students collaborate in groups to complete activity designs based on the STEAM-based mitigation project, incorporating the steps of the Engineering Design Process (EDP). The stages of the EDP included in the activity design are detailed in Table 1.

Table 1
Water Filter Project Activity Design

<table>
<tr><th>Aspect</th><th>Activities</th></tr>
<tr><td colspan="2">Problem Analysis: Jepara City is experiencing an extended dry spell with no rainfall, leaving residents struggling to find water in this emergency. The only available water source is a nearby river, but the water is too dirty to drink safely. If you were a resident of Jepara City, what steps would you take to address this issue? Design a simple water filter to purify the river water. Then, calculate the amount of river water needed to produce 1000 ml of clean water</td></tr>
<tr><td>Define the Problem</td><td>1. What problems should the citizens in Jepara city solve?</td></tr>
<tr><td>Research</td><td>2. What solutions can you offer to residents in Jepara city to overcome these problems?</td></tr>
<tr><td>Imagine</td><td>3. Considering the tools and materials available, what project will you make to solve the problem? Make some designs to deal with the problem.
4. Differentiate the order of the materials in your plans!</td></tr>
<tr><td>Plan</td><td>5. Of the different solution model designs you have made, which one is most suitable for the problem?</td></tr>
<tr><td>Create</td><td>6. Make one of the project designs that you have determined with the tools and materials that have been provided (used bottles, sand, cotton, charcoal, gravel and stones). Build the project with a maximum material thickness of 20 cm</td></tr>
<tr><td>Test and evaluate</td><td>7. Based on the project arrangement you have made in number 6, it turns out that the thickness of the cotton cannot be less than 5 cm to produce clear water. Based on this requirement, is the tool you have arranged appropriate?
• If the tool is successful, write down the thickness of each material you used!
• If the project is not successful, write down the things that need to be improved.</td></tr>
<tr><td>Redesign</td><td>8. Make improvements to projects that are not quite right, then test, evaluate and refine your project to get the best results!</td></tr>
<tr><td>Communicate</td><td>9. What is the concept of one-variable linear equations and inequalities for the filtering device?
<table>
<tr><th>Dirty water (tested)</th><th>Clean water (result)</th></tr>
<tr><td></td><td></td></tr>
<tr><td></td><td></td></tr>
<tr><td></td><td></td></tr>
<tr><td></td><td></td></tr>
</table>
If you want to get 1000 ml of clean water, how much river water do you need?
10. What mitigation efforts can be made when there is a drought and residents in the area lack clean water? Then present and explain the results of the project you have made.</td></tr>
</table>

After learning through mitigation STEAM-based projects, students are given posttest questions to determine their critical thinking skills. The posttest questions presented contain 6 indicators of critical thinking according to Ennis (1991), namely focus, reason, inference, situation, clarity, overview. In addition, the posttest questions also contain several EDP steps, namely define the problem, test and evaluate, and redesign. Before the posttest was distributed to students, expert validation and readability tests were first carried out. The posttest questions have gone through a validation process by experts to ensure their quality and suitability for the research objectives. Expert validation was carried out by one mathematics lecturer and one subject teacher who are competent in their fields. After being calculated using Aiken's validity test, the posttest question was in a very high category with a validity level of 0.93.

A readability test was also conducted to ensure that students could clearly understand the content and instructions of the questions. The readability test was conducted using an interview or discussion method, followed by one student as a respondent. The type of readability test used was a limited readability test, where the evaluation was carried out on a small scale to identify students' difficulties in understanding the questions. The posttest questions distributed were in accordance with Table 2.

Table 2
Critical Thinking Posttest Question

No	Question
1	From the results of the simple filter made, students can enter $x\ ml$ of dirty water. After the filtering process, 70% water is obtained from the volume entered. a. If the volume of clean water produced is 560 ml, transform the problem into a one-variable linear equation. b. Calculate the gross volume (x) put in. c. In making the filter, students only need to buy charcoal and cotton because other materials are in the surrounding environment without having to buy. It is known that the price of charcoal is 10,000 per kg, and the price of cotton is 5,000 per pack, so the total cost incurred to make 1 simple filter is Rp.75,000. If the amount of charcoal used to make one tool is 5 kg, how many packs of cotton are used? d. If the water you filtered is still cloudy, what needs to be modified to make it more effective? e. Do the results of the tool modifications that have been made also affect the total costs incurred? Give the reason!
2	To save costs in making water filters, one of the students took the initiative to replace cotton with stones. The number of materials needed is as follows: • Gravel: x kg • Stone: 10 kg • Charcoal: 15 kg • Sand: 8 kg To ensure that the water filter can work properly and efficiently, two requirements must be met: i. The total weight of the materials should not exceed 50 kg for easy transportation and use by the community. ii. The weight of gravel (x) should be at least twice the weight of sand to optimize the filtration process. Based on these conditions, a. Find the value of x (weight of gravel) that satisfies both conditions. b. Although changing the water filter material from cotton to stone is considered cost-effective, is the quality of the water produced the same? Give your reasons. If the quality of the water produced is not suitable for use, what do you do to make the filter produce clear and usable water?

After students were given the post-test questions as presented in Table 3, the following is an example of a student answer sheet. This answer sheet was selected to illustrate students' critical thinking skills in solving problems according to the indicators measured.

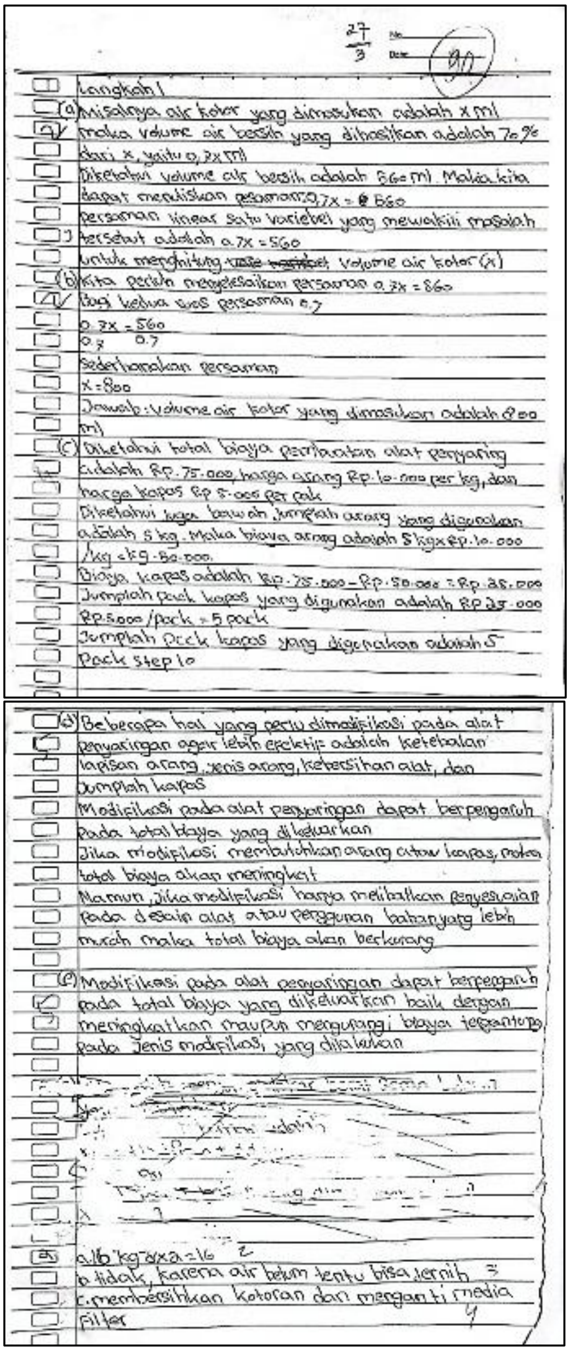

Figure 1 Student Answers.

Based on Table 2 and figure 1, questions number 1a, 1b, and 1c show the critical thinking indicators of focus, situation, and clarity. This is because in these items, students must focus on defining the problem in a case to form an equation, students must be able to collect and use relevant information from the given situation and be able to understand and explain the relationship between variables in the given problem. Several posttest items (1d, 1e, 2a, 2b, and 2c) focus on critical thinking indicators such as reasoning, inference, and evaluation. These questions require students to justify their answers, formulate conclusions based on calculations, and assess the solution processes they used. As a result, the posttest is intended to evaluate both mathematical understanding and students' critical thinking ability. To obtain an initial picture of group differences, mean posttest scores were calculated after students completed the critical thinking posttest. The experimental group achieved an average score of 70.69, compared to 56.21 for the control group. Further analysis using a t-test was then conducted to test the significance of this difference, following the fulfillment of normality and homogeneity assumptions. The test statistics used in the normality test are the Kolmogorov-Smirnov and Shapiro-Wilk tests using statistical software with a significance level of 5% or 0.05. The results of the normality test can be seen in Table 3.

Table 3.
Normality Test Result ($\alpha = 0.05$)

Class	Sig. (Kolmogorov-Smirnov)	Sig. (Shapiro-Wilk)
Experiment	0.084	0.076
Control	0.117	0.052

The results in Table 3 demonstrate that the normality assumption was satisfied for the experimental and control groups on critical thinking tasks related to equations and one-variable linear inequalities. The significance value obtained in the experimental class is greater than α = 0.05

(0.076), whereas the control class obtained 0.052. Therefore, H_0 is accepted, and H_1 is rejected. These findings indicate that the posttest scores are normally distributed. Following the normality test, a homogeneity test was conducted to examine whether the variances of the data sets were equal. Data are considered homogeneous when the significance value exceeds 0.05. In this study, homogeneity was tested using Levene's test with the aid of statistical software. The results based on the mean show a significance value (Sig.) of 0.068, which is greater than 0.05, indicating that the posttest data have homogeneous variance. As both normality and homogeneity assumptions were satisfied, a parametric t-test was subsequently employed to test the research hypothesis.

H_0: The mathematical critical thinking skills of students taught using the STEAM-based water filter project are no better than those taught using the Teacher-Centred Learning (TCL) method.

H_1: The mathematical critical thinking skills of students taught using the STEAM-based water filter project are better than those taught using the Teacher-Centred Learning (TCL) method.

A t-test was applied after confirming normality and homogeneity. The obtained Sig. (2-tailed) value of 0.00 was smaller than the significance level of 0.05, indicating a significant difference between groups. Accordingly, students exposed to the STEAM-based water filter mitigation project achieved better mathematical critical thinking outcomes than those in the TCL group. Students' positive responses to the STEAM-based project are summarized in Table 4.

Table 4
Student's Response in STEAM-Based Project Leaning Mitigation

Aspect	Statement	Response (%)				
		SA	A	F	D	SD
Aspects of mathematical ability	1. The water filter project helped me understand the concept of linear equations and inequalities of one variable.	37,9	62,1	0,0	0,0	0,0
	2. The Water Filter project helped me connect math concepts to real life.	17,2	62,1	20,7	0,0	0,0
	3. The Water Filter project was able to improve my skills in solving math problems.	27,6	41,4	20,7	10,3	0,0
	4. After making the Water Filter project, I feel more motivated to learn math.	44,8	20,7	24,1	10,3	0,0
Aspects of mitigation STEAM-based learning	5. The Water Filter project improved my understanding of the concept of disaster mitigation.	20,7	48,3	20,7	10,3	0,0
	6. I can identify potential risks and provide recommendations to reduce the impact of disasters.	37,9	27,6	27,6	3,4	3,4
	7. Through the Water Filter project, I am more concerned about disaster issues in my neighbourhood.	34,5	41,4	20,7	3,4	0,0
	8. I can ask relevant questions about the disaster mitigation process after learning through the Water Filter project.	24,1	58,6	10,3	6,9	0,0

Aspect	Statement	Response (%)				
		SA	A	F	D	SD
	9. After making the Water Filter project, I feel more confident in solving problems related to drought.	27,6	34,5	21,0	3,4	3,4
Aspects of critical thinking skills	10. I feel more critical in solving math problems after making the Water Filter project.	27,6	24,1	37,9	6,9	3,4
	11. I can collaborate with friends to analyze and solve complex problems.	44,8	41,4	10,3	3,4	0,0
	12. I am more confident in expressing my ideas and opinions.	24,1	31,0	44,8	0,0	0,0
	13. I can explain the reasoning behind the decision I made in making the Water Filter.	13,8	34,5	27,6	20,7	3,4

This study aims to evaluate the effectiveness of the STEAM-based water filter project in enhancing students' critical thinking. Accordingly, success is indicated by higher average scores in the experimental class compared to the control class, as well as positive student responses. Class VII A was taught using the STEAM-based project approach, while Class VII B followed the TCL model, leading to variations in student outcomes. In the STEAM project, students collaborated in groups (Rahmawati et al., 2019). By integrating STEAM principles through a project-based water filtration activity, students enhanced their knowledge and skills over time. In Figure 1, students have integrated the concept of STEAM mitigation into the material of linear equations and inequalities of one variable. Water filters are made using used plastic bottles arranged vertically and filled with various layers such as cotton, gravel, stones, charcoal, and sand to filter dirty water, as shown in Figure 2. Students are free to determine the arrangement of filter materials according to their ideas and creativity, so that each project made can have different design variations.

Figure 2. STEAM-Based Mitigation Water Filter Project.

The STEAM approach encourages students to integrate theory and practice in problem-solving, fostering critical thinking in the process (Rahmawati et al., 2019; Ryu et al., 2019). This is further supported by student responses in Table 5, where 37.9% of students strongly agreed and 62.1% agreed that the water filter project helped them understand the concept of linear equations and inequalities. In STEAM-based mitigation project learning, students are required to define problems and gather information to find solutions. Their ability to analyze observations and answer questions effectively reflects the development of their critical thinking skills (Apriliana et al., 2018).

The problems presented in the project should be relevant to real-life situations, allowing students to apply contextual knowledge from their daily experiences to enhance their critical thinking skills (Rahmadani et al., 2023). This is supported by student responses, which indicate that the water filter project helped bridge mathematical concepts with real-world applications, with 17.2% of students strongly agreeing, 62.1% agreeing, and 20.7% remaining uncertain. Furthermore, student responses reveal that STEAM-based mitigation project learning fosters collaboration, enabling students to work together in analyzing and solving complex problems. The response percentages show that 44.8% strongly agreed, 41.4% agreed, 10.3% were uncertain, and 3.4% disagreed. These findings demonstrate that STEAM-based project learning not only strengthens critical thinking skills but also promotes essential 21st-century competencies, such as collaboration and communication (Mansur et al., 2022; Pramasdyahsari et al., 2025a). Jolly (2017) outlines the steps of the EDP in STEAM learning, which include defining the problem, conducting research, imagining solutions, planning, creating, testing and evaluating, redesigning, and communicating findings. This aligns with research by Lippard et al. (2017), which confirms that following EDP steps effectively enhances students' critical thinking abilities.

The findings of this study demonstrate that the integration of a STEAM-based water filter mitigation project had a significant impact on students' mathematical critical thinking skills. Students in the experimental group, who engaged in the STEAM project, achieved a higher average posttest score (70.69) compared to the control group taught through a Teacher-Centred Learning (TCL) approach (56.21). The results of the t-test confirmed that this difference was statistically significant ($p < 0.05$), indicating that STEAM-based project learning effectively fostered students' ability to think critically in mathematics. The low mean score in the control group indicates that conventional scientific learning, as implemented in this study, was insufficient to foster higher-order critical mathematical thinking, which requires sustained engagement with complex, contextual, and open-ended problems. Although the control group followed the nationally recommended scientific learning model, this approach did not explicitly emphasize sustained critical thinking processes, which may explain the lower performance on critical thinking measures. Moreover, the substantial difference between groups can be attributed to the contrasting cognitive demands of the two approaches. The STEAM-based mitigation project required students to identify problems, design solutions, test ideas, and evaluate outcomes, whereas the control group primarily engaged in routine exercises and structured questions with predetermined answers.

These results align with previous research highlighting the effectiveness of project-based and STEAM-integrated learning in improving higher-order thinking skills, particularly critical thinking and problem-solving (Beers, 2011; Çevik & Özgün-Koca, 2022; Khasanah et al., 2024; Rahmawati et al., 2019;). By embedding the Engineering Design Process (EDP) within the water filter project, students were encouraged to define problems, propose multiple solutions, test and evaluate their ideas, and refine their designs. This iterative process mirrors authentic problem-solving in real-world contexts, thereby strengthening critical thinking indicators such as focus, reason, inference, and evaluation (Ennis, 1991; Moore et al., 2014).

The low performance of the control group should not be interpreted as a lack of learning, but rather as an indication that the scientific learning approach, as implemented in this study, provided limited scaffolding for higher-order critical mathematical thinking. The posttest measured general indicators of reasoning, inference, and evaluation and did not assess knowledge specific to water filtration. Both groups were taught the same mathematical content, ensuring that differences in performance were not due to unequal content exposure. A key distinction lies in the engineering component of the STEAM-based project. Students in the experimental group engaged in an engineering design process that required them to design, construct, test, and refine water filtration prototypes. These iterative activities compelled students to evaluate ideas, justify decisions, interpret results, and revise solutions, which directly correspond to core dimensions of critical thinking. In contrast, the control group primarily engaged in teacher-directed instruction and routine exercises, offering fewer opportunities for sustained problem solving and evaluation. Consequently, the large performance gap reflects differences in cognitive demand and learning experiences rather than test bias.

Furthermore, the analysis of student responses further supports these findings. A majority of students reported positive perceptions of the project, particularly in terms of connecting mathematical concepts to real-life situations, increasing motivation to learn mathematics, and improving their ability to collaborate with peers. Notably, more than 60% of students agreed or strongly agreed that the project enhanced their understanding of one-variable linear equations and inequalities, as well as their confidence in applying mathematics to practical challenges. These responses indicate that STEAM-based mitigation projects not only enhance cognitive skills but also promote affective and social dimensions of learning, such as motivation, collaboration, and confidence (Lou et al., 2017; Thuneberg et al., 2018).

In addition, the integration of disaster mitigation themes into the STEAM framework broadened students' awareness of environmental and social issues. Through the water filter project, students were able to recognize the importance of clean water access during drought conditions, identify risks, and propose relevant mitigation strategies. This demonstrates the potential of STEAM learning to cultivate not only academic competencies but also civic responsibility and sustainability awareness, aligning with the goals of education for sustainable development (UNESCO, 2017; Kaya & Elster, 2019).

Despite the positive results, this study has some limitations. The small sample drawn from one school may restrict the generalization of the findings, and the posttest-only design does not reveal long-term effects or transfer of critical thinking skills. Further research should consider larger samples, longitudinal approaches, and examine the influence of STEAM-based mitigation projects on broader mathematical literacy outcomes (Bybee, 2013; Quigley & Herro, 2016).

The results suggest that integrating STEAM principles into real-world mitigation projects provides a promising pathway for improving students' mathematical critical thinking. When mathematics is presented through contextual and hands-on experiences, students not only enhance their thinking skills but also better appreciate its relevance to everyday challenges.

IV. Conclusion

Participation in the STEAM-based water filter mitigation project was found to significantly strengthen students' critical thinking compared to teacher-centred instruction, and students responded positively to the learning experience. The project-based STEAM process helps students connect mathematical concepts with real situations and develop skills in analysing problems, designing and evaluating solutions, and improving their work. Beyond critical thinking, this approach also nurtures creativity, collaboration, and communication, as well as sensitivity to disaster mitigation and environmental issues. Teachers can strengthen students' critical thinking by structuring STEAM projects around the engineering design cycle and using brief evidence-based reflection prompts after each testing phase. Given the scope of this study, future research should expand the sample size and explore additional mathematical topics in junior high school.

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